Numerical Analysis of Stress Distribution of the Actual Size Wood Bearing Wall in Relation to the Framing Type*

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Abstract——The stress distribution of the actual size panel (90 cm × 240 cm) tested by two types of loading is analyzed numerically in relation to the framing type. The stress distributions of the sixteen types of panels with horizontal and/or vertical stiffeners are not affected by the different in number and the combination of the stiffeners, while the deformations of these panels are 1.3 times larger in horizontal loading without tie rod (test type B) than in horizontal loading with tie rods (test type A) regardless of the stiffener's types, and the efficiency of the vertical stiffeners on the deformation of the panels is twice as much as that of the horizontal stiffeners. As for the panels with braces the stress distributions are affected a little by the difference in number and the direction of the braces, and the deformation of the panel in test A is much smaller when the compression brace is used.

Introduction

At present the stressed-skin panel is one of the most important structural components of the prefabricated wooden houses and there are many difficult problems remained in the sense of designing and estimating the performance of the house rationally.

In the previous paper[1] stress distributions of plywood bearing wall panels with a simple framing without any stiffeners subjected by three different types of loadings respectively were calculated numerically by the finite element method, and characteristics of the respective types of loading and efficiency of the thickness of framing were discussed.

In this paper, the stress distributions and deformations of the actual size panels (90 cm × 240 cm) with the different types of stiffeners or braces are analyzed numerically.

On the efficiency of the stiffeners on the rigidity of the panels, R. YAMAI[2] carried out the racking tests using load-bearing wall panels of full scale and reported that in both glued and nail-glued panels without opening racking load corresponding to the shearing deformation 1/100 radian was little affected by the difference in the types of stiffeners. Furthermore, T. MARUYAMA *et al.*[3] and H. SUGIYAMA *et al.*[4]

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also reported the similar conclusion. In this paper, the result of numerical analysis is compared with the above experimental results.

Method of Analysis

The computer program used in this paper is the plane linear analysis program which is based on the finite element method, and the same as was used in the previous paper[1]. All computations were performed on a FACOM 230–75 and M-190 computer at the Data Processing Center, Kyoto University.

Wall panels used in the analysis are of 240 cm high and 90 cm long. As can be seen in Figure 1, all of the frames, horizontal and vertical stiffeners, and braces are all of 5 cm wide and 5 cm thick Western Hemlock. The skin is of 3-ply 0.77 cm thick lauan plywood. The panels are constructed in nineteen different types of stiffeners or braces as illustrated in Figure 2; a panel without any stiffeners or braces, three panels with one to three horizontal stiffeners, three panels with one to three vertical stiffeners, nine panels with different combination of horizontal and vertical stiffeners, and three panels with one or two braces. The vertical stiffeners and the compression brace are cut in the horizontal stiffeners and the tension brace respectively. It is assumed here that the connection between the skin and the frame(or stiffeners, braces) is perfect and neither slip nor relative motion occurs at the inter-

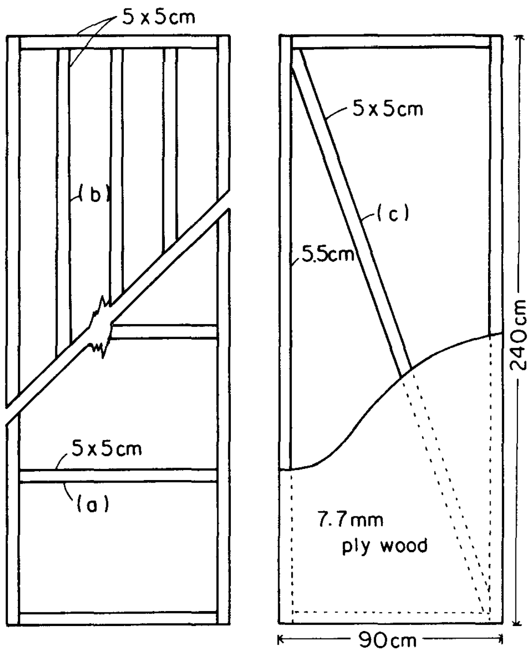

Fig. 1. Panel Details.
(a) Horizontal stiffener
(b) Longitudinal stiffener
(c) Bbrace

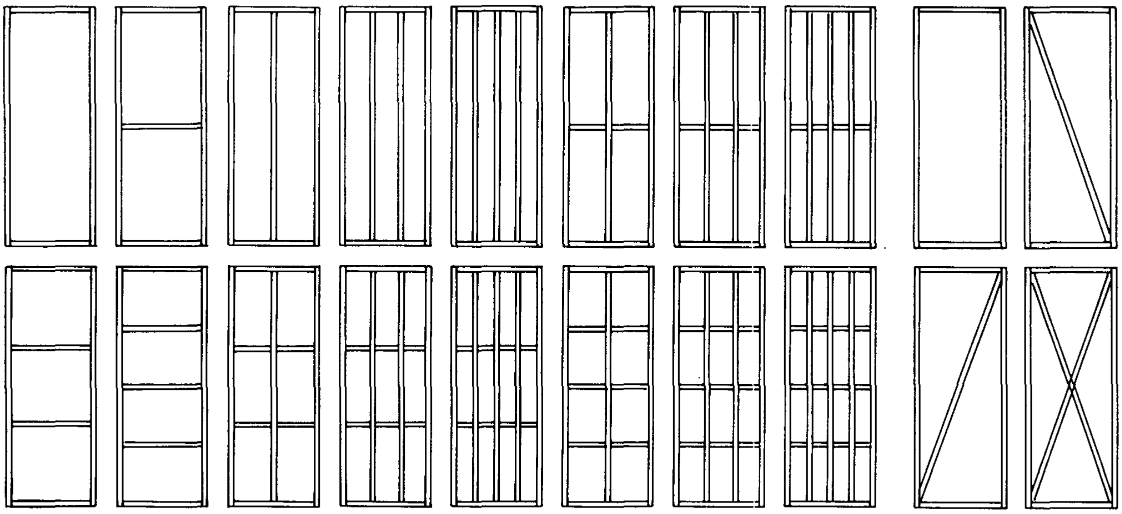

Fig. 2. Types of framing.

Table 1. Elastic constants of the framing (frames, stiffeners, braces) and the skin used in the calculation.

Member	Supposed material	Elastic constant
Framing	Western Hemlock	$E_L = 109000$ kg/cm^2 $E_T = 4400$ kg/cm^2 $\mu_{LT} = 0.51$ $G_{LT}^* = 6300$ kg/cm^2
Skin	3-ply lauan plywood	$E_1 = 90000$ kg/cm^2 $E_2 = 37000$ kg/cm^2 $\mu_{12} = 0.135$ $G_{12}^* = 3200$ kg/cm^2

* G from E_{15} using Jenkin's formula.

face. This is usually achieved, in practice, with nail-glued or press-glued panels. The calculations are done on the assumpiton that the all connections between frames, stiffeners, and braces are attached rigidly. The elastic constants used in the calculation are shown in Table 1. The elastic constants at the overlapped part of the skin and the frame (or stiffeners, braces) is determined by the following equation,

$$E = \frac{E_s \times t_s + E_f \times t_f}{t_s + t_f}$$

where E_s is elastic constant of skin, E_f is elastic constant of the frame (or stiffeners, braces), t_s is thickness of the skin, and t_f is thickness of the frame (or stiffeners, braces).

Then the panels were idearized into imaginary finite elements as indicated in Figure 3. Figure 3(a) shows the mesh pattern of the panels with stiffeners, which consists of 1,440 elements and 784 nodes, while, Figure 3(b) shows that of the panels

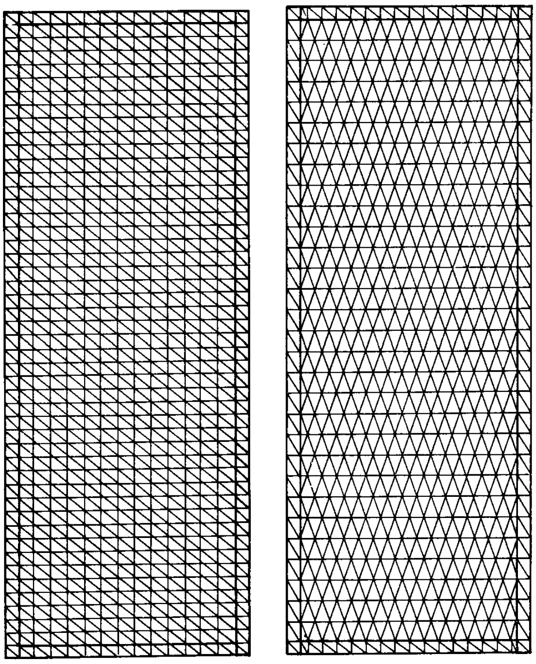

Fig. 3. Idealization of the panels with many imaginary finite elements.

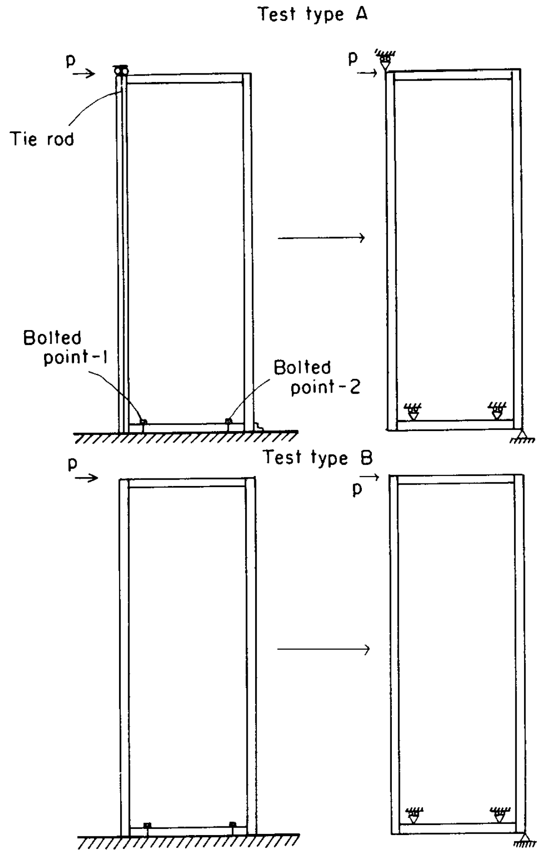

Fig. 4. Idealization of the test methods used in this study.

with braces which consists of 1,122 elements and 612 nodes.

Computation was done for the panels loaded by two types of racking tests; test type A and test type B. Test type A is well-known as ASTM E72[5] and has been used mainly in the United States and England. Taking the vertical compressive load by the roof or the upper floors into consideration, two tie rods are applied at loaded end, *i. e.* one tie rod on each side of the specimen to prevent an upward movement of this edge. Test type B has been used generally as the rigidity and shear strength test of the wood based panel for wall of the prefabricated house in our country, which is specified as JIS A 1414[6]. The above two test methods were idealized as show in Figure 4.

Result and Discussion

Strictly speaking, the stress distributions in the stiffener type panels and the brace type panels can not be discussed on the same ground since those respective mesh patterns are different each other. Nevertheless, the stress distributions of both can be discussed at the same time because the stress distributions of the panels

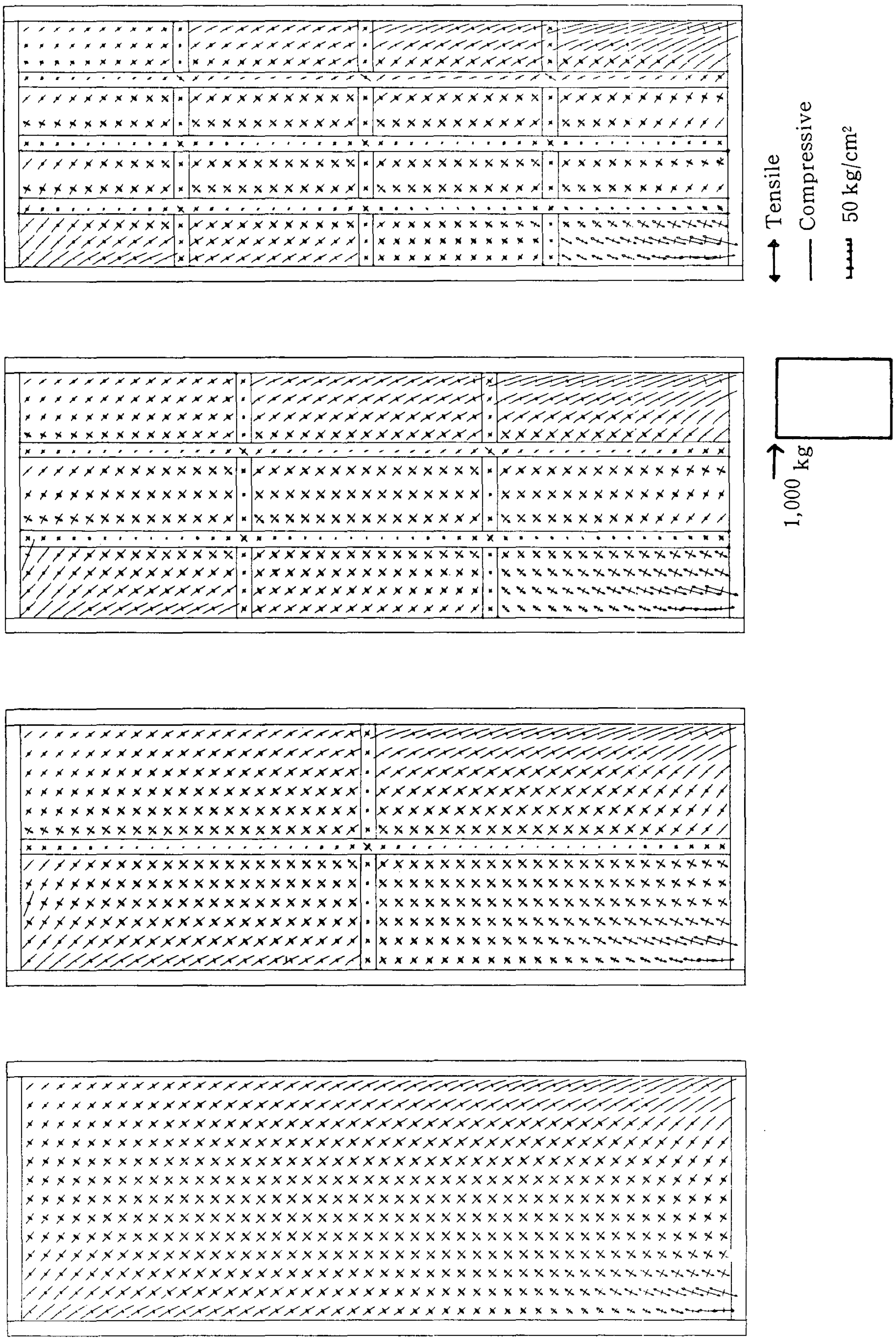

Fig. 5-1. Principal stresses of a stiffener type panel subjected to a horizontal compressive load 1 ton by test type A.

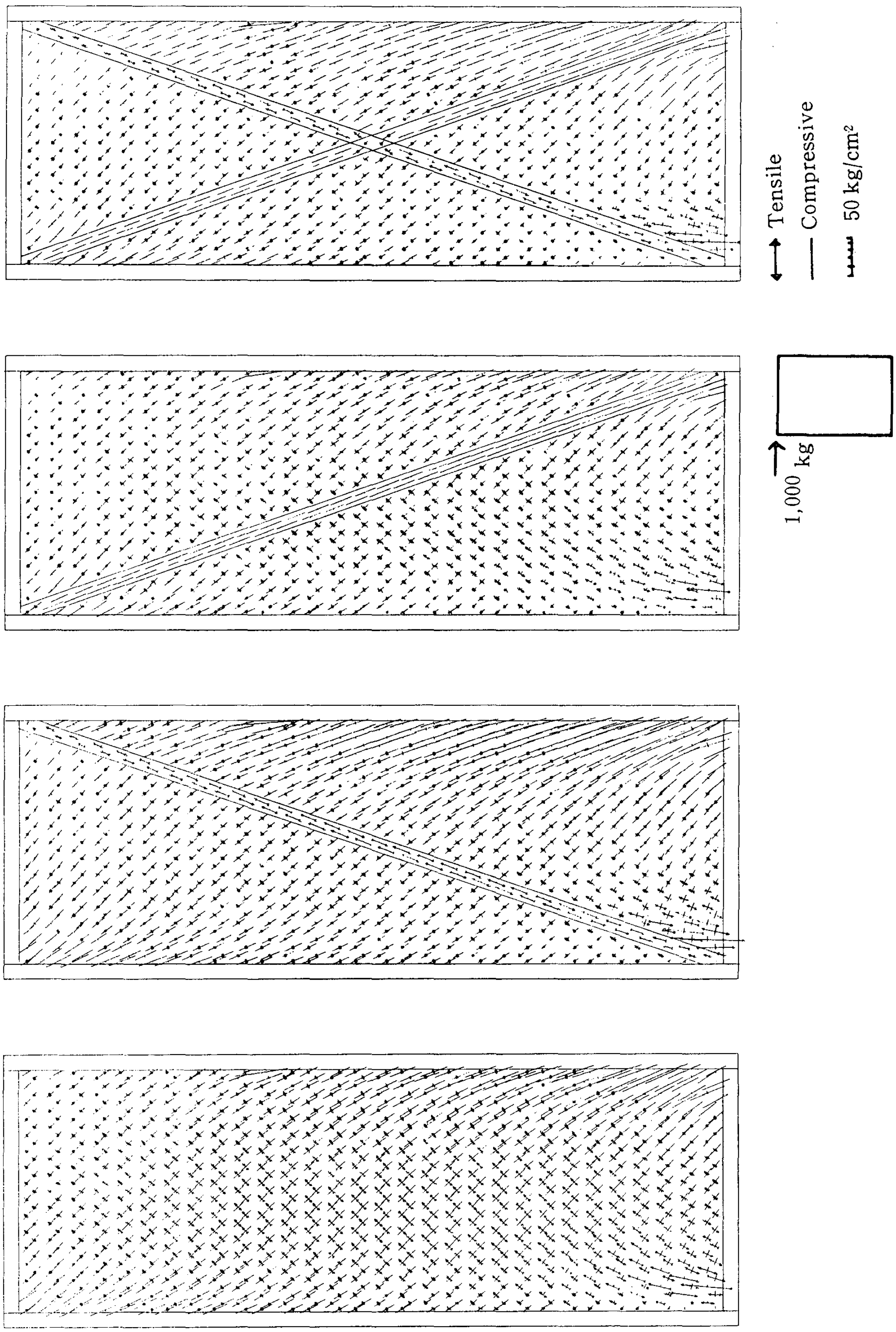

Fig. 5-2. Principal stresses of a brace type panel subjected to a horizontal compressive load 1 ton by test type A.

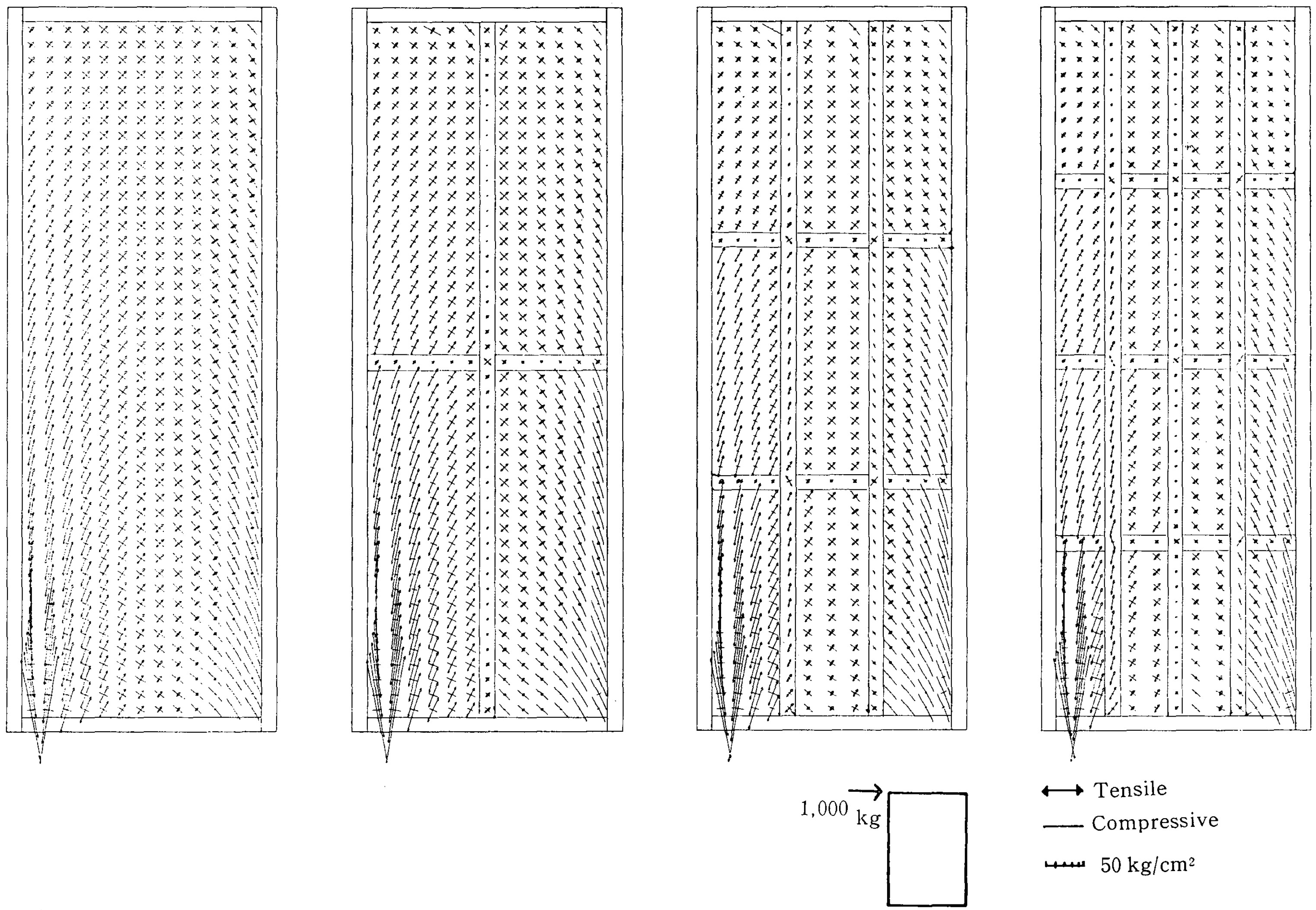

Fig. 6-1. Principal stresses of a stiffener type panel subjected to a horizontal compressive load 1 ton by test type B.

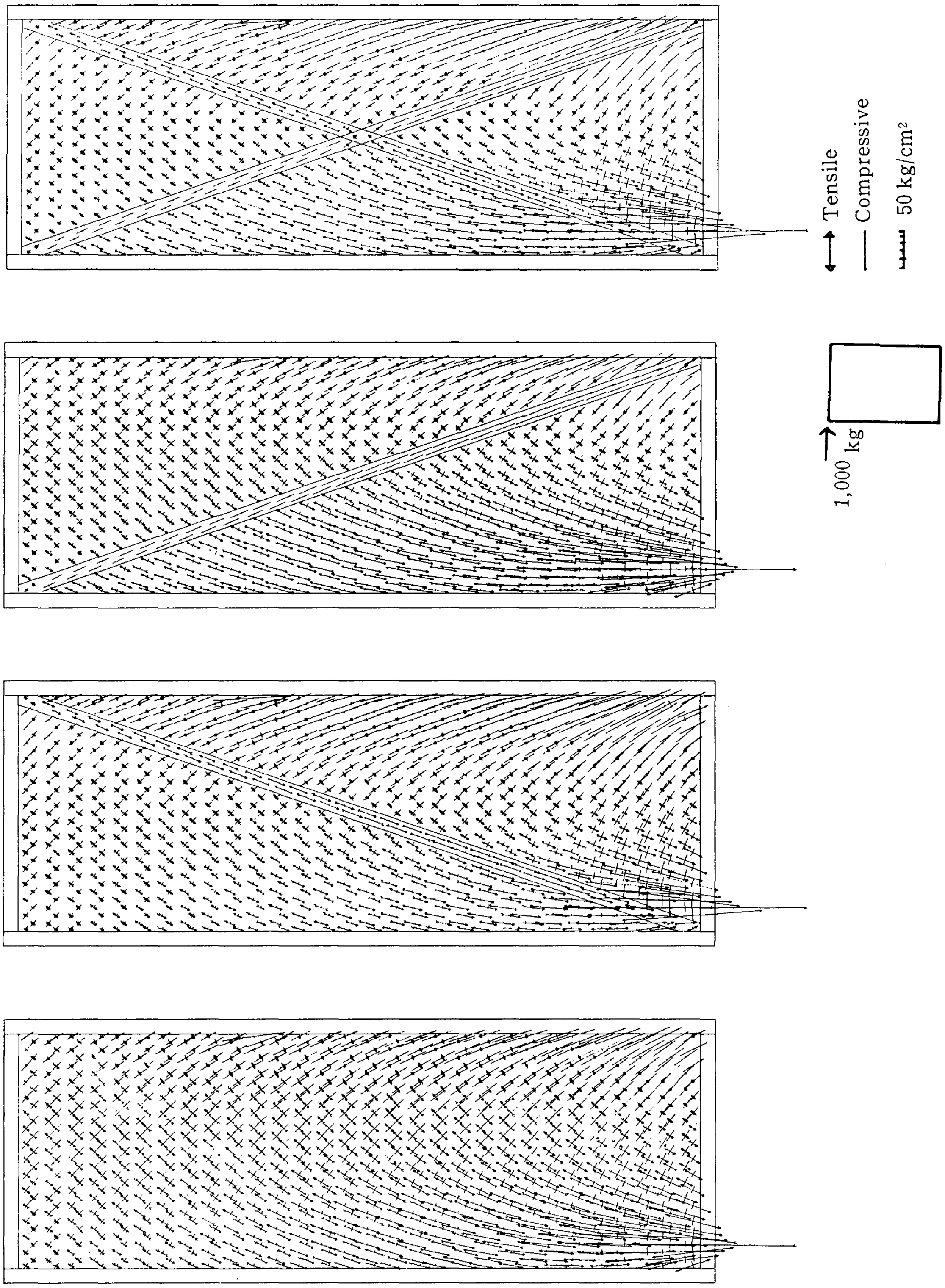

Fig. 6-2. Principal stresses of a brace type panel subjected to a horizontal compressive load 1 ton by test type B.

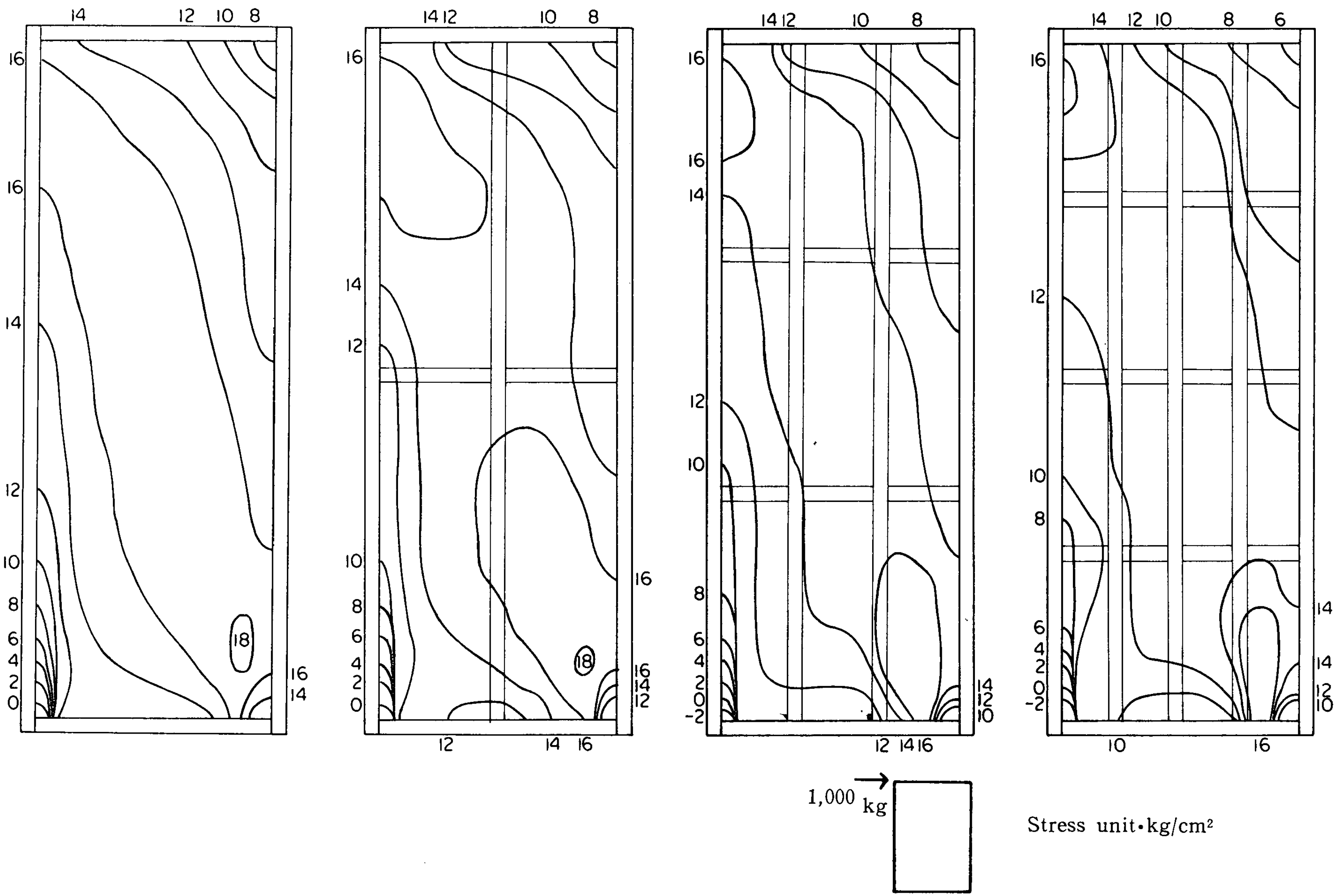

Fig. 7-1. Contour plot of shear stress τ_{xy} of a stiffener type panel subjected to a horizontal compressive load 1 ton by test type A.

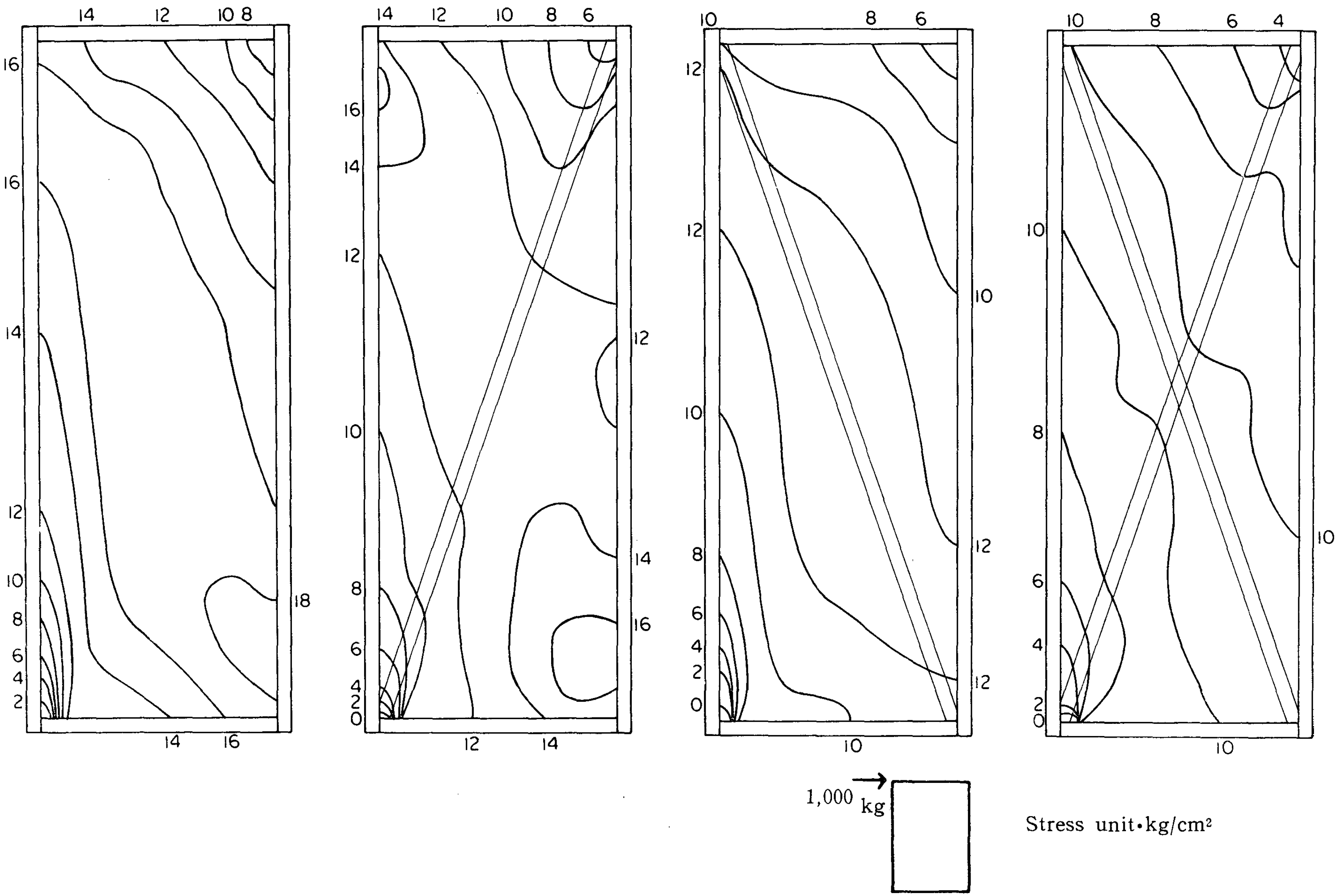

Fig. 7-2. Contour plot of shear stress τ_{yx} of a brace type panel subjected to a horizontal compressive load 1 ton by test type A.

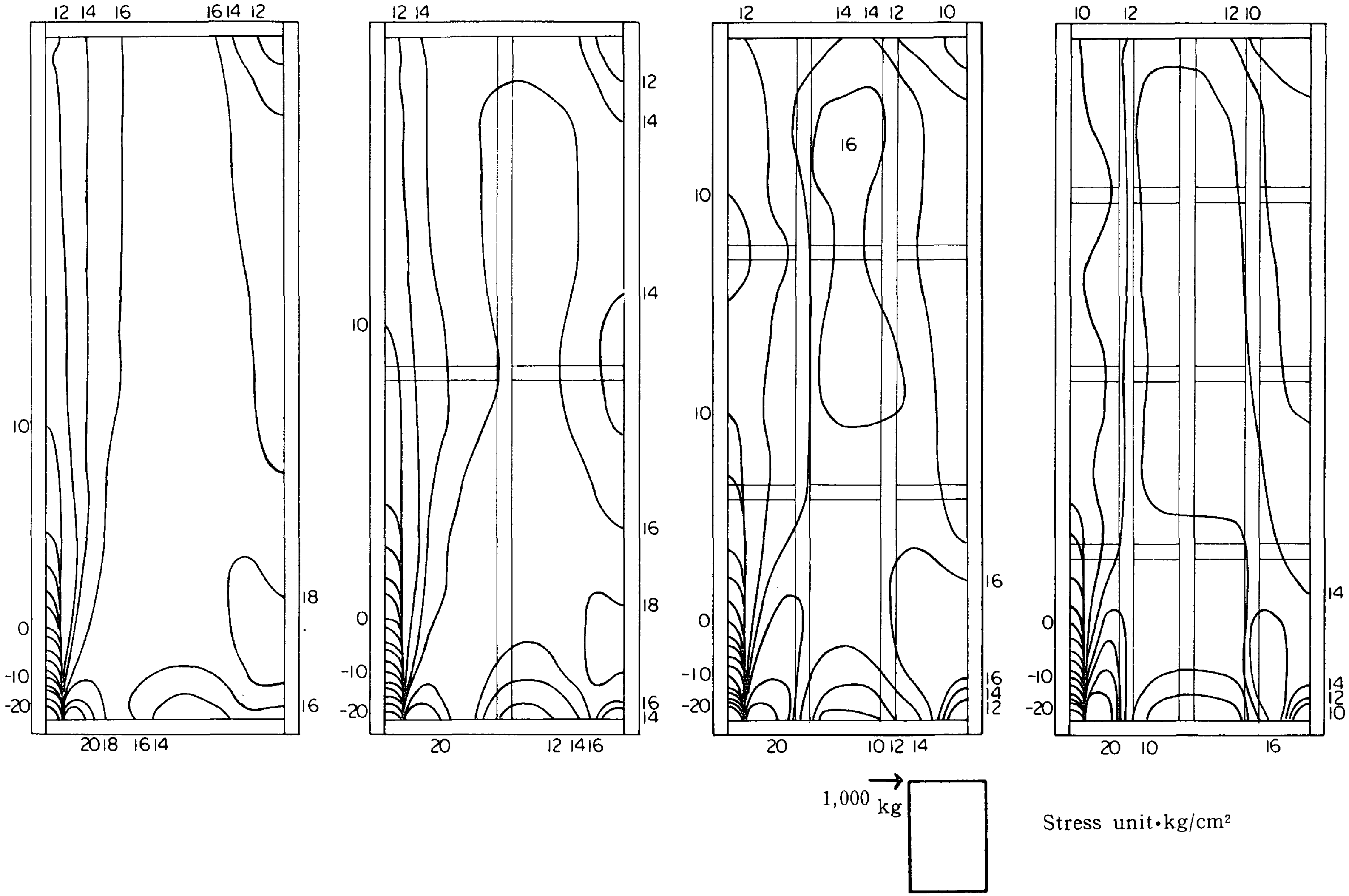

Fig. 8-1. Contour plot of shear stress τ_{xy} of a stiffener type panel subjected to a horizontal compressive load 1 ton by test type B.

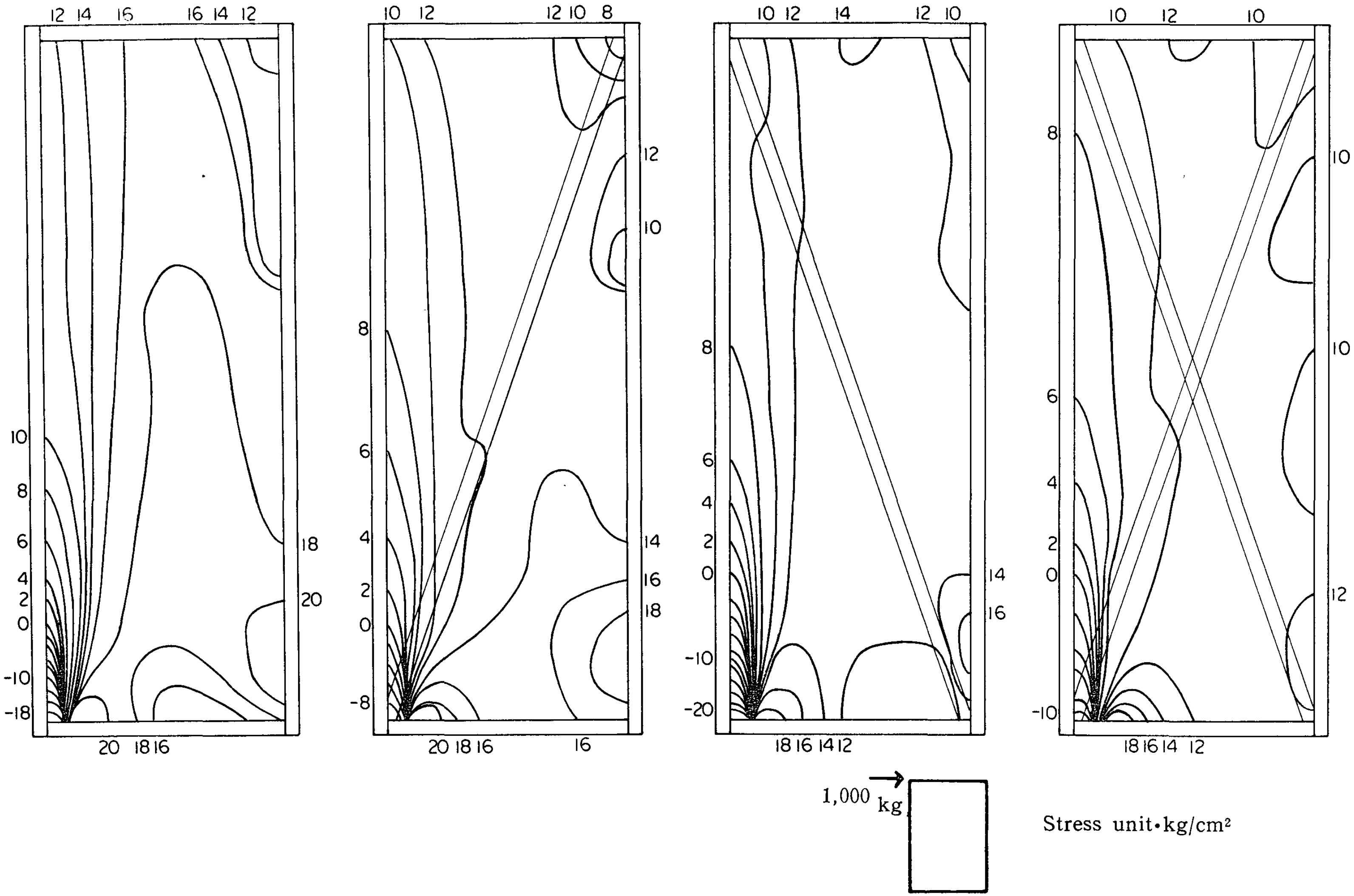

Fig. 8-2. Contour plot of shear stress τ_{xy} of a brace type panel subjected to a horizontal compressive load 1 ton by test type B.

without any stiffeners or braces computed by these two different mesh patterns was almost same.

Although the stress distributions of the sixteen types of panels with stiffeners were analyzed, only the stress distributions of four typical cases were illustrated because the differences among the stress distributions of all these types of panel were very little These four are 1) a panel without any stiffener, 2) a panel with one horizontal stiffener and one vertical stiffener, 3) a panel with two horizontal stiffeners and two vertical stiffeners, and 4) a panel with three horizontal stiffeners and three vertical stiffeners.

Figure 5 and 6 show the principal stresses of these panels caused by the test type A and B respectively, of which horizontal compressive load was lton at the upper corner. The lines with arrow and without arrow show tensile stress and compressive stress respectively. The principal stresses of the panels with stiffeners are not affected by the different in number and the combination of the stiffeners. As for the panels with braces the principal stresses are affected just a little by the difference in number and the combination of the braces. At the bolted point-1 just under the loading point (see Figure 4), there are higher tensile stresses than any other parts of the panel. On the other hand, at the bolted point-2, there are higher compressive stresses than any other parts. In the panels with stiffeners, the tensile stresses at bolted point-1 by test type B are twice as large as that by test type A and in everywhere except for the parts adjasent to the bolted points, principal stresses by test type A and B are almost uniform and same, while in the panels with braces, principal stresses by test type A and B are not same. In the part adjacent to the bolted point-1, tensile stresses by test type B are about three times as large as that by test type A.

Figure 7 and 8 show the contour plots of shear stress τ_{xy} of the panels tested by test type A and B respectively. The stiffeners and loading conditions of the panels are same as mentioned above. The shear stress τ_{xy} is slightly affected by the differences among the construction of stiffeners or braces. At the bolted point-1, a distinct and sudden discontinuity of the shear stress τ_{xy} is observed in both cases of type A and B. Beside, the degree of discontinuity by test type B is higher than the one by test type A.

Figure 9 and Table 2 show the amount of displacement of loading point for the sixteen types of panels with stiffener subjected to a horizontal compressive load of 1 ton test type A and B respectively. The numbers in parentheses are the relative values of the horizontal displacement at the loading point when that of the panel without stiffeners is taken as 100. The deformations in both case of test type A and B decrease linearly with increase of the number of horizontal and vertical stiffeners. In all constructions of the stiffeners and braces the deformations of panels by test

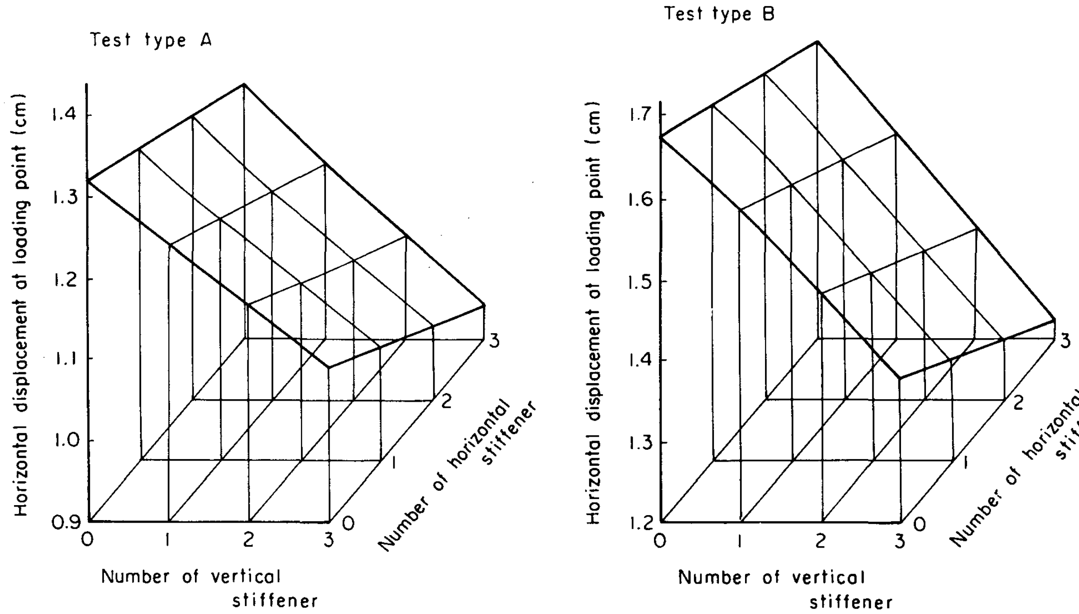

Fig. 9. Horizontal displacement at loading point of the stiffener type panels which are subjected to a horizontal compressive load 1 ton by test type A and B.

type B show 1.3 times as much as the deformations of panels by test type A. The efficiency of the vertical stiffener on the shear deformation of panels is twice as much as that of the horizontal stiffener. The percentage displacements of the panels with the same construction of stiffeners by test type A and B are almost equal.

Table 3 shows the displacements at loading point of the four types of panels with braces which are subjected to a horizontal compressive load of 1 ton by test type A and B respectively. The deformation of the panel by test type A decreases remarkably when the compression brace is used. One compression brace has an effect equivalent to the combination of three vertical and three horizontal stiffeners (compare percent displacements in Table 2 and 3). In the deformation of the panel by test type B the efficiency of a compression brace is not so remarkable as that by test type A, but it has an effect equivalent to the combination of two vertical and three horizontal stiffeners.

Conclusion

It was analyzed numerically that, on the whole, the stress distributions of all panels which are subjected to a horizontal compressive load of 1 ton by test type A and B, are little affected by the stiffeners or the braces, while the deformation decreases with the stiffeners and braces. Consequently, the racking load which corresponds to the displacement of 1/100 radian increase in proportion to the increase of the number of stiffeners and braces. As for the panels with stiffener, the increase is 2% to 28%. In respect of the rigidity of the panel, the vertical stiffeners are more effective than

Table 2. Horizontal displacement at loading point of the stiffener type panels which are subjected to a horizontal compressive load 1 ton by test type A and B. The parenthesized numbers show the relative values of the displacments when that of the panel without stiffeners is taken as 100.

Test type A

Number of vertical stiffener	Number of horizontal stiffener			
	0	1	2	3
0	1.319 cm (100)	1.285 cm (97.4)	1.250 cm (94.8)	1.215 cm (92.1)
1	1.243 cm (94.2)	1.202 cm (91.1)	1.159 cm (87.8)	1.117 cm (84.7)
2	1.166 cm (88.4)	1.121 cm (85.0)	1.073 cm (81.4)	1.028 cm (77.0)
3	1.091 cm (82.7)	1.042 cm (79.6)	0.991 cm (75.2)	0.944 cm (71.6)

Test type B

Number of vertical stiffener	Number of horizontal stiffener			
	0	1	2	3
0	1.677 cm (100)	1.642 cm (98.0)	1.605 cm (95.6)	1.567 cm (93.4)
1	1.588 cm (94.7)	1.544 cm (92.1)	1.499 cm (89.4)	1.454 cm (86.7)
2	1.483 cm (88.4)	1.434 cm (85.5)	1.384 cm (82.5)	1.337 cm (79.7)
3	1.377 cm (82.1)	1.324 cm (78.9)	1.271 cm (75.8)	1.222 cm (72.9)

Table 3. Horizontal displacement at loading point of the brace type panels which are subjected to a horizontal compresive load 1 ton by test type A and B. The number in parentheses are the relative values of the horizontal displacement at the loading point when that of panel without braces is taken as 100.

Brace type / Test type	Without any brace	Tension brace	Compresion brace	Tension and compresion braces
Test type A	1.352 cm (100)	1.123 cm (83.1)	0.981 cm (72.6)	0.858 cm (63.5)
Test type B	1.804 cm (100)	1.474 cm (81.7)	1.457 cm (80.8)	1.243 cm (68.9)

the horizontal stiffeners. The increase in rigidity of the panels with braces extends over 17% to 36%, which is much higher in effect than that in the case of panels with stiffeners. It is shown that the compression brace is more effective than the tension brace in the test type A. This is in accord with the result of L. O. ANDERSON's report[7] in which he concluded that the brace should be used in compression. On the contrary, the maximum racking load are supposed to be similar, since the stress distributions of all panels at the same load are almost equal. The above mentioned results by the numerical analysis correspond fairly well to the experimental results reported by R. YAMAI[2], T. MARUYAMA *et al.*[3], and H. SUGIYAMA *et al.*[4].

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